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Visualization of polarization and electrical charges using Atomic Force Microscopy

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In this tutorial, I will explain the basic principles of AFM (contact mode and ac-mode) starting from topography acquisition. Then, I will lay out the foundation of piezoresponse force microscopy (PFM), where we use the piezoelectric strain as the marker of polarization vector. This will lead to the discussion of various contributions to the strain induced by the voltage applied to the tip, such as electrostatic force (or capacitive force) induced indentation (or non-contact vibration of the cantilever), electrochemical strain, flexoelectric strain, electrostrictive strain, polarization switching induced strain, joule heating induced strain as well as Lorentz force induced deflection. In addition to all of these tip-sample interactions, one should not neglect the electrostatic force interaction between the cantilever and the sample. With all of the contributions sorted out, I will discuss about vertical and lateral PFM to build 3D vector polarization map using angle-resolved PFM. In addition, dual ac resonance tracking PFM, band excitation PFM, Switching Spectroscopy PFM will also be briefly introduced. Other markers such as screening charges are being used to map polarization vectors, which led to the invention of Charge Gradient Microscopy (CGM) as well as Scanning Resistive Probe Microscopy (SRPM). Furthermore, I will discuss electrochemical strain microscopy (ESM) and conducting AFM (C-AFM) as well as Kelvin Probe Force Microscopy (KPFM)/Electrostatic Force Microscopy (EFM), which will provide valuable information about the transport/diffusion properties of dielectric materials. All of these advanced AFM techniques will add insight into the multiscale electrical properties of dielectric materials, which will be part of our grand vision of Materials and Molecular Modelling, Imaging, Informatics and Integration (M3I3).